



MONASH University

Accident Research Centre

POLICE VEHICLES: ROLLOVER STABILITY ANALYSIS (Phase 1 Project)

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Sept. 2000

Report No. 184



VICTORIA POLICE

REPORT FOR VICTORIA POLICE

Corporate Services Division, Victoria Police Centre
637 Flinders Street Melbourne

MONASH UNIVERSITY ACCIDENT RESEARCH CENTRE
REPORT DOCUMENTATION PAGE

Report No.	Date	Project period	Pages
184	Sept. 25 th 2000	May – Sept. 2000	48

Title and sub-title:

Police Vehicles: Rollover stability analysis (Phase 1 project)

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Sponsoring Organisation(s):

This project was funded by Victoria Police

ABSTRACT

Recent concerns regarding the handling performance of police vehicles (particularly the Holden Commodore divisional van) led to the police requesting Monash University Accident Research Centre (MUARC) to, firstly, conduct an analysis of vehicle handling and stability for different vehicle types in their fleet, and secondly, to assist in defining selection and performance criteria for police vehicles. The first phase of this work has been carried out and is the subject of this report.

The work comprised two main tasks: (i) analysis of the police vehicle accident database, and the vehicle database, with regard to determining the incidence and rate of rollover involved crashes for each vehicle type; and (ii) determine stability and dynamic handling characteristics of a range of police vehicles using Tilt Table test, and Steady State Turning and a Double Lane Change Manoeuvre. Thirteen vehicles were tested for centre of gravity height (Tilt Table) and a further 6 for handling evaluation. The tests were carried out by the Army Engineering Agency (AEA) Mechanical Laboratories, at the Army's Monegetta Proving Grounds.

The analysis of the available crash data identified that the Holden Commodore divisional van had a rollover rate significantly higher than that identified for Commodore and Falcon Sedans and the earlier Falcon divisional vans. The Toyota Landcruiser models had a calculated rollover rate higher than the Commodore divisional van, with the Rodeo 4x2 divisional van being higher still. For the Commodore divisional van, using this data, together with the results from the Tilt Table stability tests, Steady State Turning Test and the Double Lane Change manoeuvre, indicates that the rollover issue is predominantly related to the height of the vehicle's center of gravity. The additional mass arising from the addition of prisoner pods to the base vehicles (Rodeo and Commodore) has resulted in reduced rollover stability characteristics for these vehicles.

Disclaimer The views expressed here are those of the authors.	MUARC - Accident Research Centre, PO Box 70A, Monash University VIC 3800. Telephone: +61 3 9905 4371, Fax: +61 3 9905 4363
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ACKNOWLEDGMENTS

The assistance of the following organizations and staff are gratefully acknowledged:

- Commander Gary Jamieson, S/Sgt Terry Basford, Mr Ross McGrice, Mr Ray Smith and staff from Victoria Police ;
- The Army Engineering Agency, Mechanical Laboratory, Monegetta for the conduct of the stability and handling tests.

1. INTRODUCTION

Recent concerns regarding the handling performance of police vehicles (particularly the Holden Commodore divisional van) led to the police requesting Monash University Accident Research Centre (MUARC) to, firstly, conduct an analysis of vehicle handling and stability for different vehicle types in their fleet, and secondly, to assist in defining selection and performance criteria for police vehicles. The first phase of this work has been carried out and is the subject of this report.

The work comprised two main activities:

1. Analysis of the police vehicle accident database, and the vehicle database, with regard to determining the incidence and rate of rollover involved crashes for each vehicle type.
2. To examine stability and dynamic handling characteristics of a range of police vehicles, including the Holden Commodore divisional van. The Victoria Police identified 13 vehicles to be tested for centre of gravity height and a further 6 for handling evaluation.

The results from the database analyses of actual rollover crashes and the handling tests could then be compared and used to identify probable vehicle stability (or handling) problems in the police vehicle fleet.

2. METHOD

2.1 Analyses of the Police Vehicle and Accident Databases

2.1.1 Determination of the incidence of rollover crashes

The Police Transport Branch made the police vehicle accident database available to MUARC. Although this database does not explicitly categorise vehicle accidents by type of crash, a search was made of the text data to identify any crashes where the descriptions contained the word “rolled” or variations thereof.

The accident database was searched for the period from beginning of 1990 to June 2000.

2.1.2 Determination of the rate of rollover crashes

The Transport Branch’s police vehicle database contains records of all pre-delivery, active (current) and retired vehicles (sold). Fields in this database include the date vehicles are purchased, sold date, last recorded odometer reading¹, and average mileage²/month.

The statistical software package SPSS was used to analyse this database for the period 1990 to June 2000, to determine for each vehicle model the exposure in ‘vehicle-

¹ Not given for 850 vehicles, out of the total of 12,424 (station wagons, trucks, and vehicles prior to 1990 were excluded from this analysis. Data was analysed for the period 1990- July 2000.

² This information was available for 70% of the 12,424 vehicles in the data set.

months'. Vehicle-months are the sum of the total numbers of months that particular model types were in service. For example if there were 10 Holden divisional vans operating for a period of 12 months each, then the total "vehicle months" is $10 \times 12 = 120$.

The exposure value 'vehicle-months' could then be used to compare the rollover rate for each vehicle model involved in rollover crashes. In addition, as the various vehicle models have different usage, rollover crash rate based on kilometres travelled was also determined.

2.2 Stability and Handling Tests

A vehicle rollover can be attributed to either of two vehicle parameters: the relationship between the centre of gravity height and the track width, and /or the handling characteristics of the vehicle. In order to establish if either vehicle parameter is causing a rollover, both must be measured and ranked within a sample group. The Victoria Police identified 13 vehicles to be tested for centre of gravity height and a further 6 for handling evaluation.

2.2.1 Vehicle Static Stability Tests

Measurements selected for the assessment of the Victoria Police vehicles were Axle Loading, Mass, Wheelbase, Track, Centre of Gravity location and Tilt Table Rollover angle. Two metrics were used to rank the rollover propensity of the supplied police Vehicle Tilt-table test and the Stability Factor. All the above tests were conducted at the Army Engineering Agency (AEA) Proving Ground, Monegetta.

The tilt table test provides a measure of the level of lateral acceleration (force) needed to lift the inside wheels off the ground and overturn a vehicle. Such 'centripetal' acceleration may arise when the vehicle is cornering or changing direction such as during a quick lane change manoeuvre. Also the tangential function of the overturn angle is a measure of the frictional coefficient necessary to trip the vehicle if it is sliding sideways. If the vehicle overturn angle is low then it is quite possible to roll a vehicle over on a dry bitumen road, simply by sliding the back of the vehicle out (fishtail).

2.2.2 Vehicle Handling Tests

The Handling tests selected for the assessment of the Victoria Police vehicles were Steady State Turning and a Double Lane Change Manoeuvre.

The Steady State Turning test is based on recognised International Organisation for Standardisation (ISO) test procedures. The Double Lane Change Manoeuvre was selected because it is commonly used by the automotive industry to simulate an accident avoidance manoeuvre.

The test vehicle was fitted with instrumentation that measured lateral acceleration, handwheel angle and torque, vehicle roll angle, forward velocity and lateral velocity both in the front and rear of each vehicle. For safety reasons, a limit of 0.7 of the calculated rollover lateral acceleration was used as a limit for all Handling Testing. A zero run was performed prior to all tests, which enabled instrumentation offsets to be determined. All tests were conducted at the AEA Proving Ground, Monegetta.

3. RESULTS AND DISCUSSION

3.1 Incidence of Police Vehicle Rollover Crashes

A total of 39 crashes involving rollover were identified, as set out in Table 1.

Vic Police.	Model Description	Acc_Date	No of vehicles in fleet at crash date
MWO170	COMMODORE EXEC VP 3.8 AUTO SED	23/06/1993	176
NVY509	COMMODORE EXEC VS2 3.8 AUTO SED	17/12/1996	292
EHU292	FALCON GL 3.9MPI AUTO SEDAN	10/14/91	738
EJU351	FALCON GL 3.9MPI AUTO SEDAN	11/13/91	704
MWF294	FALCON GL VAN 4.1L COL AUTO.	01/11/91	221
MWO324	FALCON GL VAN 4.1L COL AUTO.	28/02/1993	229
MWO046	FALCON GLI EB2 4.0MP AUTO SED	4/02/1994	305
ZVA697	FORD SEDAN	11/21/90	?
NYW722	FUTURA EF2 4.0MP AUTO SEDAN	15/08/1997	79
MAQ687	FUTURA EL1 4.0MPI AUTO SEDAN	25/11/1998	287
EFQ786	HOLDEN SEDAN	7/01/1998	?
MAH398	HOLDEN VS2 3.8L COL AUTO UTE	24/12/1996	54
MAJ834	HOLDEN VS2 3.8L COL AUTO UTE	19/08/1997	117
OHO295	HOLDEN VS2 3.8L COL AUTO UTE	22/09/1997	113
MAL228	HOLDEN VS2 3.8L COL AUTO UTE	27/11/1997	142
MAT295	HOLDEN VS3 3.8L COL AUTO UTE	3/05/1999	183
MAU599	HOLDEN VS3 3.8L COL AUTO UTE	5/07/1999	204
MAV819	HOLDEN VS3 3.8L COL AUTO UTE	24/09/1999	170
MAV904	HOLDEN VS3 3.8L COL AUTO UTE	28/10/1999	184
MAV913	HOLDEN VS3 3.8L COL AUTO UTE	11/03/2000	147
MAV841	HOLDEN VS3 3.8L COL AUTO UTE	6/04/2000	152
MAZ324	HOLDEN VS3 3.8L COL AUTO UTE	20/05/2000	152
OQW817	JACKAROO 4X4 SE V6 3.2MPI AUT4O WAG	5/11/1998	7
PIZ921	L/CRUISER 42DSL 4X4 MAN WAG HZJ105R	23/09/1999	35
MVE574	L/CRUISER 42DSL 4X4 MAN WAG HZJ80R	5/09/1995	36
MVE711	L/CRUISER 42DSL 4X4 MAN WAG HZJ80R	17/05/1997	26
OLI565	L/CRUISER 42DSL 4X4 MAN WAG HZJ80R	19/03/1998	49
MWN624	L/CRUISER 4X4 HJ75 LWB 3S 4.0L MAN	6/03/1992	11
MWF589	L/CRUISER 4X4 HJ75 LWB4.2D 3ST MAN	8/03/1993	4
ELV575	L/CRUISER 4X4 HJ75 LWB4.2D 6ST MAN	26/08/1993	4
MWF630	NISSAN 4WD	21/02/1992	?
PRE599	PATROL 4X4 ST 4.5EFI MANUAL WAGON	11/04/2000	14
MAH325	POLARIS INDY XLT TUR SNOWMOBILE	4/08/1999	
MAR849	RODEO C/CAB 3.2 V6 4X2 PET/AUT0	19/02/2000	35
MAY411	RODEO C/CAB 3.2 V6 4X2 PET/AUT0	20/03/2000	46
MAY494	RODEO C/CAB 3.2 V6 4X2 PET/AUT0	21/04/2000	46
MAY495	RODEO C/CAB 3.2 V6 4X2 PET/AUT0	23/05/2000	49
FRY541	RODEO CREWCAB 4X2 PETROL AUTO	14/04/1997	5
MWF666	TOYOTA 4WD	09/22/91	?

Table 1 Police vehicle crashes identified as involving rollover (period 1990 - June 2000)

Table 1 shows the model type, date of crash, and the number of vehicles in service in the police fleet at the time.

Table 2 (taken from Table 1) summarises the frequency of the rollover-involved crashes by vehicle model type. Noticeable from this data, are the 11 rollover involved crashes for the Commodore divisional van, 5 for the Rodeo 4x2, and 7 for Toyota Landcruiser models.

Model Description	No involved	Total for model type
COMMODORE EXEC VP 3.8 AUTO SED	1	
COMMODORE EXEC VS2 3.8 AUT SED	1	2
FALCON GL 3.9MPI AUTO SEDAN	2	2
FALCON GL VAN 4.1L COL AUTO.	2	2
FALCON GLI EB2 4.0MP AUTO SED	1	
FUTURA EF2 4.0MP AUTO SEDAN	1	
FUTURA EL1 4.0MPI AUTO SEDAN	1	3
HOLDEN VS2 3.8L COL AUTO UTE	11	11
JACKAROO 4X4 SE V6 3.2MPI AUTO WAG	1	1
L/CRUISER 42DSL 4X4 MAN WAG HZJ105R	1	
L/CRUISER 42DSL 4X4 MAN WAG HZJ80R	3	
L/CRUISER 4X4 HJ75 LWB 3S 4.0L MAN	1	
L/CRUISER 4X4 HJ75 LWB4.2D 3ST MAN	1	
L/CRUISER 4X4 HJ75 LWB4.2D 6ST MAN	1	7
PATROL 4X4 ST 4.5EFI MANUAL WAGON	1	1
RODEO C/CAB 3.2 V6 4X2 PET/AUT0	4	
RODEO CREWCAB 4x2 PETROL AUTO	1	5
<i>Subtotal – for known model type</i>	34	34
POLARIS INDY XLT TUR SNOWMOBILE	1	1
GENERIC - HOLDEN SEDAN -	1	
GENERIC FORD SEDAN -	1	
TOYOTA 4WD - GENERIC	1	
NISSAN 4WD - GENERIC	1	4
Total	39	39

Table 2 Vehicles involved in rollover accidents³ by model type
(period 1990- June 2000, from police vehicle accident database)

³ Because crash type is not explicitly classified in the police vehicle accident database, it is not possible to establish whether all rollover involved crashes have been identified.

3.2 Rate of Rollover Involved Crashes by Vehicle Model

The rates of vehicle crashes can be compared using a number of exposure measures. Typical values used are rates based on the number of registered vehicles, and rates based on kilometres travelled.

3.2.1 Rollover rates based on vehicles in the fleet (vehicle-months)

The first and primary exposure measure used here is the exposure measure ‘vehicle-months’, which represents the total time exposure of the model type⁴ in the fleet. Table 3 presents the “rollover rate” using vehicle months as the exposure⁵ measure (also see Figure 1).

Vehicle Description	Sum Of Vehicle Months	No Of Rollovers	Rollover Rate per 10,000 vehicle-months
COMMODORE SEDAN	81021	2	0.25
FORD FALCON SEDAN	83526	5	0.60
FORD FALCON DIVVY VAN	21003	2	0.95
LANDCRUISER WAGON 105R	4310	1	2.3
PATROL WAGON	3673	1	2.7
JACKAROO WAGON	1619	1	6.2
L/CRUISER WAGON 80R	4517	3	6.6
L/CRUISER HARDTOP LWB	2835	3	10.6
HOLDEN DIVVY VAN	6842	11	16.6
RODEO 4X2	968	5	51.6
TOTAL		34	

Table 3 Summary of police vehicle rollover rate per 10,000 vehicle-months, by vehicle model type

Thus the lowest rollover rate is for the Commodore sedan (0.25), with the highest calculated for the Rodeo 4x2 (52).

For the Holden divisional van, the rate of 16.6 compares with the much lower rate of 0.95 calculated for the previous Ford Falcon divisional van, that is a factor of 17:1.

⁴ See App. 3 for description of model types and grouping.

⁵ The calculated rollover rate is per 10,000 vehicle months. Rollover rate equals the ratio [number of rollovers]/[total vehicle-months] multiplied by 10,000.

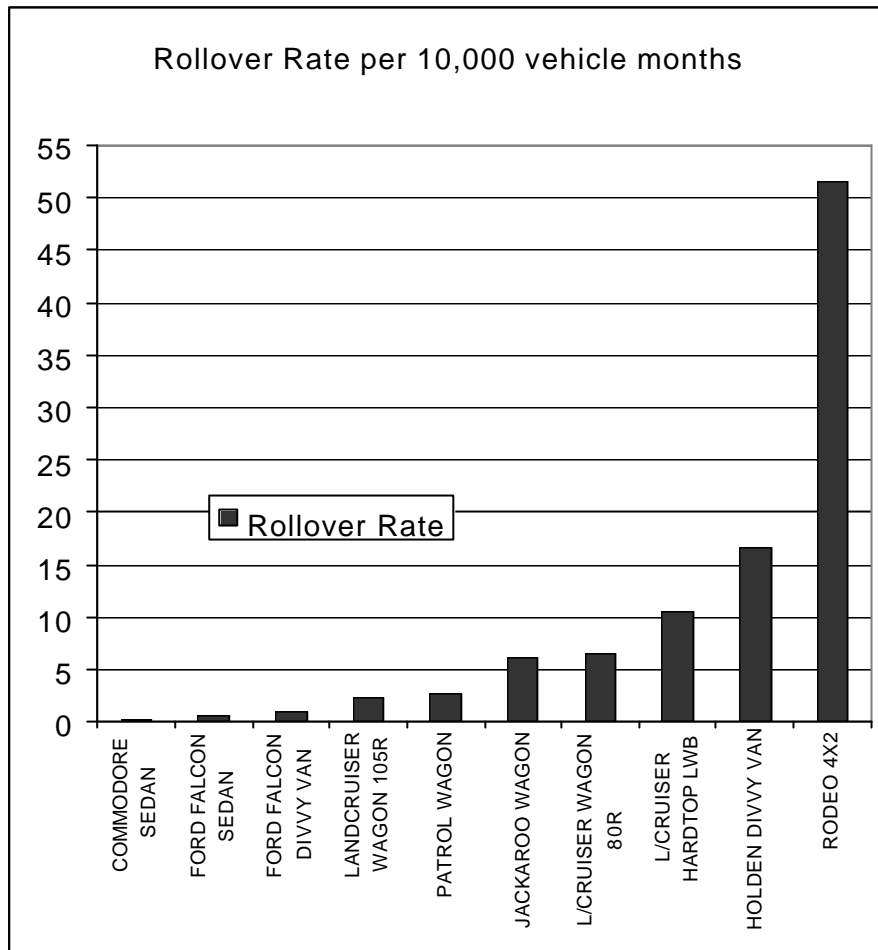


Figure 1 Rollover crash rate per 10,000 vehicle months, by model type

3.2.2 Rollover rates based on kilometres travelled

This exposure measure recognises that vehicle usage varies for different models and that some models may be on the road more than others. This measure of exposure can be captured (at least in part) by using the distance travelled (kilometres) as the exposure measure. The rollover rate has been calculated from the police vehicle database, and is summarised in Table 4 and shown in Figure 2.

Vehicle Description	Sum of kilometres travelled	No. vehicles in group	Average no. kms for life of vehicle	No. of Rollovers	rate per 10million kms
COMMODORE SEDAN	248,792,877	5,429	45,827	2	0.08
FORD FALCON DIVVY VAN	98,654,036	1,217	81,063	2	0.20
FORD FALCON SEDAN	206,902,045	4,168	49,641	5	0.24
PATROL WAGON	8,308,873	124	67,007	1	1.20
JACKAROO WAGON	5,200,340	120	43,336	1	1.92
HOLDEN DIVVY VAN	33,751,425	738	45,734	11	3.26
L/CRUISER WAGON 80R	8,665,933	98	88,428	3	3.46
L/CRUISER WAGON 105R	1,782,835	61	29,227	1	5.61
L/CRUISER LWB	4,919,467	47	104,670	3	6.10
RODEO 4X2	2,701,725	67	40,324	5	18.51
TOTAL	619,679,556	12,069		34	

Table 4 Rollover rate per 10 million kms travelled

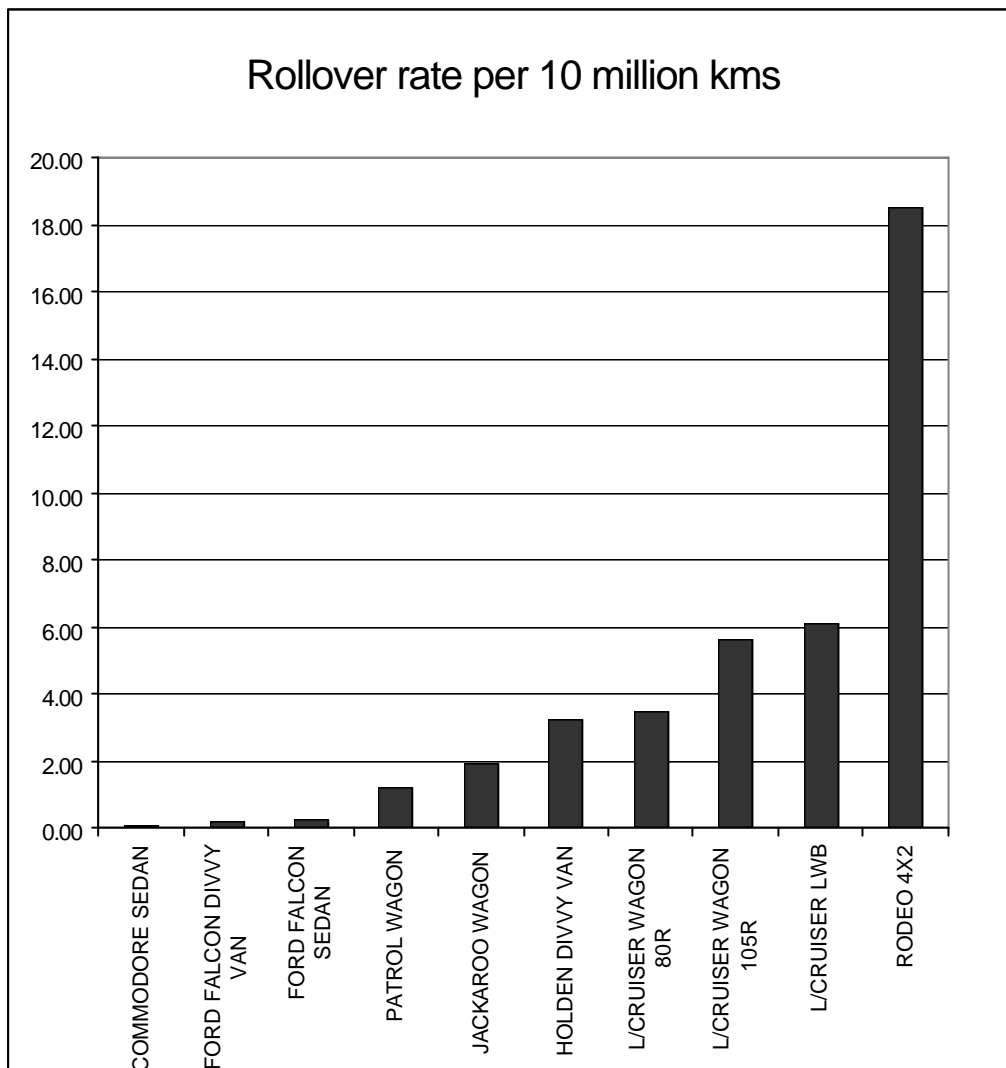


Figure 2 Graph of rollover rate per 10 million kms travelled (see Table 4)

Based on this exposure measure, the Commodore and Ford sedans have a low rollover rate of less than 0.24 rollovers per 10 million kms travelled; the Ford Divvy van has a similar value of 0.20. The Commodore divisional van has a significantly higher rate of 3.26, with the Toyota Landcruiser higher still at 3.46 to 6.1). The highest rate is for the Rodeo 4x2, which is 18.5.

This calculated rollover rate for the Holden divisional van (3.26) is 16 times higher than that of the previous model Ford Falcon divisional van (0.2). This relative rollover rate of 16:1 is consistent with the ratio of 17:1, calculated when using vehicle-months as the exposure measure given in Section 3.2.1.

To determine whether the rate of rollovers differs for different vehicle types a statistical test called the Chi-square goodness of fit test was performed on the rollover data relative to the total kilometres traveled. The large Chi-square result showed that there was strong evidence to suggest that there is a significant difference in the rate of rollovers among vehicle types (refer App. 4). The vehicles contributing to this large

X^2 result are the Holden Divvy van and the category making up all the four-wheel drives and the Rodeo 4x2. In other words these are the vehicles which have a higher than expected rate of rollovers (based on their relative exposure).

3.3 Stability Tests Results

The Victoria Police identified 13 vehicles to be tested for centre of gravity height.

The vehicle measurements selected for the assessment of the Victoria Police vehicles were Axle Loadings, Mass, Wheelbase, Track, Centre of Gravity location and Tilt Table Rollover angle.

Two metrics were used to rank the rollover propensity of the supplied police vehicle tilt-table test (see Figure 1) and the Stability Factor. All the above tests were conducted at the Army Engineering Agency (AEA) Proving Ground, Monegeetta.

3.3.1 Tilt Table results

The results of the tilt table tests are listed and ranked in Table 5.

Ranking	Vehicle	Angle	Tan(angle)
1	Holden Rodeo 4x4 Divisional Van	37.0	0.754
2	Toyota Landcruiser Troop Carrier	38.9	0.807
3	Holden Rodeo 2x4 Divisional Van	39.3	0.818
4	Mazda E2000 Van	39.9	0.836
5	Toyota Landcruiser Wagon	42.2	0.907
6	Holden Commodore Divisional Van	42.9	0.929
7	Holden Rodeo 4x4 Utility	43.7	0.956
8	Holden Rodeo 2x4 Utility	44.8	0.993
9	Ford Falcon AU Divisional Van	45.4	1.014
10	Ford Falcon Divisional Van	48.3	1.122
11	Holden Commodore Utility	49.2	1.159
12	Ford Falcon AU Utility	51.6	1.262
13	Holden Commodore Sedan	52.0	1.279

Table 5 Summary of the Tilt Table results for the 13 police vehicles. Ranking is from 'least stable' to 'most stable'.



Figure 3 View showing vehicle undergoing Tilt table test at Monegeetta

3.3.2 Stability Factor

The Stability Factor is derived from circular motion theory, and is calculated from the track width and the centre of gravity height using equation 1.

$$\text{Stability Factor} = \text{Track Width} / (2 \times \text{Centre of Gravity Height}) \quad (1)$$

In the Mengert study of rollover accidents 40,000 cases involving 40 different types of vehicle were analysed. Eleven different factors were utilised to examine rollover propensity, including; Stability Factor, wheel base, age of driver, alcohol/drug use, seatbelt use, rural location, urban location, road geometry, driver error, tracking vs sliding and road surface condition (dry/wet/snow). Stability Factor was clearly the most compelling item with an excellent correlation to rollover, further analysis resulted in a relationship between Rollover Probability and Stability Factor.

$$\text{Rollover Probability} = 100 / (1 + \text{Stability Factor}^{6.9}) \quad (2)$$

The results for the 13 vehicles tested are presented in Table 6.

Ranking	Vehicle	Angle	Tan(angle)	Stability Factor	Rollover Risk - Mengert
3	Holden Rodeo 2x4 Divisional Van	39.3	0.818	0.888	69.47
2	Toyota Landcruiser Troop Carrier	38.9	0.807	0.896	68.01
4	Mazda E2000 Van	39.9	0.836	0.899	67.55
1	Holden Rodeo 4x4 Divisional Van	37.0	0.754	0.901	67.23
5	Toyota Landcruiser Wagon	42.2	0.907	1.034	44.28
7	Holden Rodeo 4x4 Utility	43.7	0.956	1.069	38.72
6	Holden Commodore Divisional Van	42.9	0.929	1.078	38.72
8	Holden Rodeo 2x4 Utility	44.8	0.993	1.092	35.32
9	Ford Falcon AU Divisional Van	45.4	1.014	1.157	26.77
10	Ford Falcon Divisional Van	48.3	1.122	1.25	17.66
11	Holden Commodore Utility	49.2	1.159	1.271	16.02
12	Ford Falcon AU Utility	51.6	1.262	1.357	10.85
13	Holden Commodore Sedan	52.0	1.279	1.507	5.57

Table 6 Summary of the Mengert analysis results for the 13 police vehicles. Ranking is from 'highest to lowest' rollover risk.

The Mengert Study graph (Figure 4), plots the 13 vehicles tested and also plots the results from Table 3 (Rollover rate per 10,000 vehicle months).

This graph (also see Table 6) indicates that the Holden Commodore divisional van has a 'probability of being involved in a rollover' of about double that of the old Falcon divisional van (38% vs 18%), and double that of the Commodore ute from which it is derived. The Rodeo divisional vans have a very high rating of nearly 70%, indicating quite adverse rollover stability characteristics. The significantly increased rollover risk for the modified police divisional van version (with the added pods) compared with the base utility variants of the Commodore and Rodeo vehicles, is clearly seen from these results.

3.3.3 Rear Suspension Air Springs

Analysis of the background information on the Commodore divisional vans supplied, indicated that the pressure in the rear suspension air springs varied from left to right in some of the vehicles involved in rollovers. It was considered that this could be a contributing factor and was further evaluated by measuring the rear spring air pressure of 24 Commodore divisional vans.

The measured airbag pressure was found to vary randomly from left to right and varied from 0 to 60psi. Nominally the air bag pressure should be set to 40psi during regular maintenance.

A variation in pressure could affect the handling of the vehicle and additional testing was incorporated in the dynamic program to examine the effect on the handling of the Commodore divisional van air bag pressures of 0psi left and 40 psi right.

Mengert Study

"Statistical Estimation of Rollover Risk"

Aug 1989, DOT-TSC-NHTSA-89-3

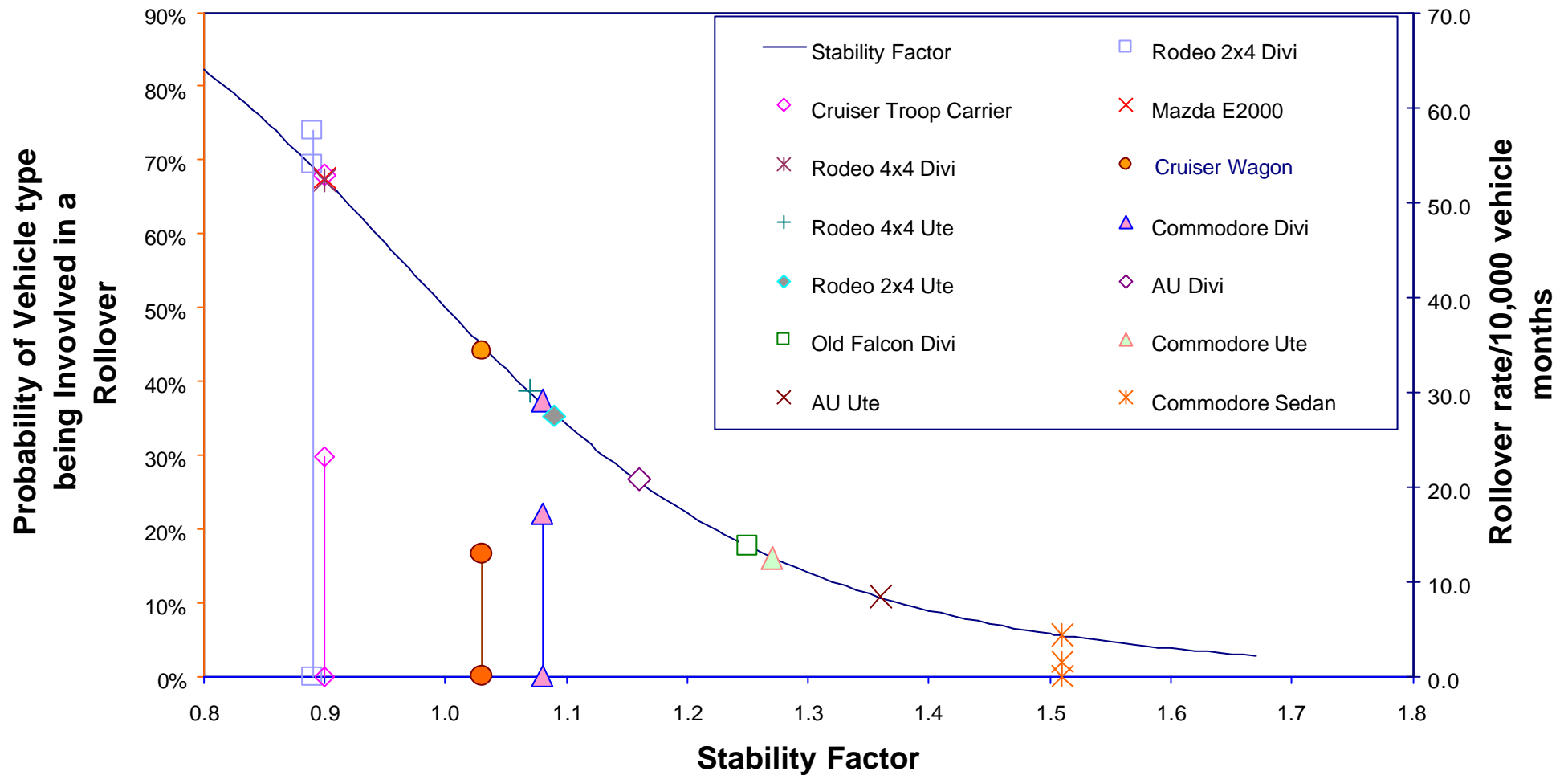


Figure 4 Mengert Study – Rollovers risk and stability factor. Plot of results for the 13 vehicles tested.

3.4 Vehicle Handling Tests

The Handling tests selected for the assessment of the Victoria Police vehicles were Steady State Turning and a Double Lane Change Manoeuvre. The Steady State Turning test is based on recognised International Organisation for Standardisation (ISO) test procedures. The Double Lane Change Manoeuvre was selected because it is commonly used by the automotive industry to simulate an accident avoidance manoeuvre.

The test vehicle was fitted with instrumentation that measured lateral acceleration, handwheel angle and torque, vehicle roll angle, forward velocity and lateral velocity both in the front and rear of each vehicle.

A limit of 0.7 of the calculated rollover lateral acceleration was used as a limit⁶ for all Handling Testing. A zero run was performed prior to all tests, which enabled instrumentation offsets to be determined.

All tests were conducted at the AEA Proving Ground, Monegetta.

3.4.1 Steady State Turning Tests

Steady State Turning Tests were conducted on a radius of 50 m in accordance with ISO 4138 “Passenger cars – Steady state circular driving behaviour – Open-loop test procedure”. The surface used for the tests was dry bituminous asphalt.

The aim of these tests was to assess the steady state understeering/oversteering characteristics of the vehicle.

Normal road vehicles should possess a steady state understeering characteristic, whereby the driver is required to apply additional handwheel angle as vehicle speed increases through the turn (positive understeer gradient as shown in Figure 5 below).

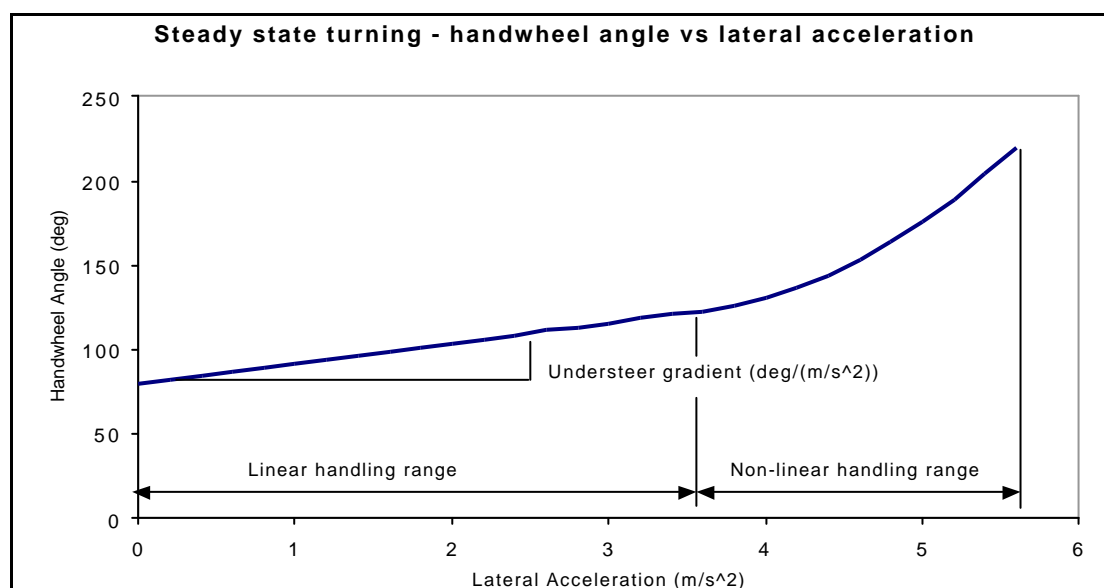


Figure 5 Steady State Turning – Understeer gradient by constant radius method

⁶ Tests to the limit of stability require outriggers fitted to the vehicle to prevent actual rollover, and hence help ensure safety for the test drivers.

As the lateral acceleration level goes beyond the linear handling range, it is considered desirable that the understeer gradient gradually increases to warn the driver that the limit of cornering is fast approaching. On the other hand an oversteering vehicle requires the driver to unnaturally “reduce” the amount of steering input (rotate handwheel in the opposite direction to the desired turn to reduce the handwheel angle) as vehicle speed increases.

In the limiting oversteer case, considerable “opposite lock” on the handwheel may be required to prevent the sideslip angle (vehicle attitude) increasing rapidly and to avoid spinning the vehicle.

The results of the Steady State Turning Test which give the Lateral Acceleration vs the Driver’s Steering Wheel Angle, are summarised in Figure 6. The relative order of the vehicles in this plot is in agreement with the stability ranking found in the Mengert profile (Figure 4).

The Landcruiser results illustrate a desirable trend with a knee at about 0.5 of the rollover lateral acceleration, the gradient response after the knee increases non-linearly. All other vehicles are only starting to illustrate a knee at 0.7 of their respective rollover lateral accelerations.

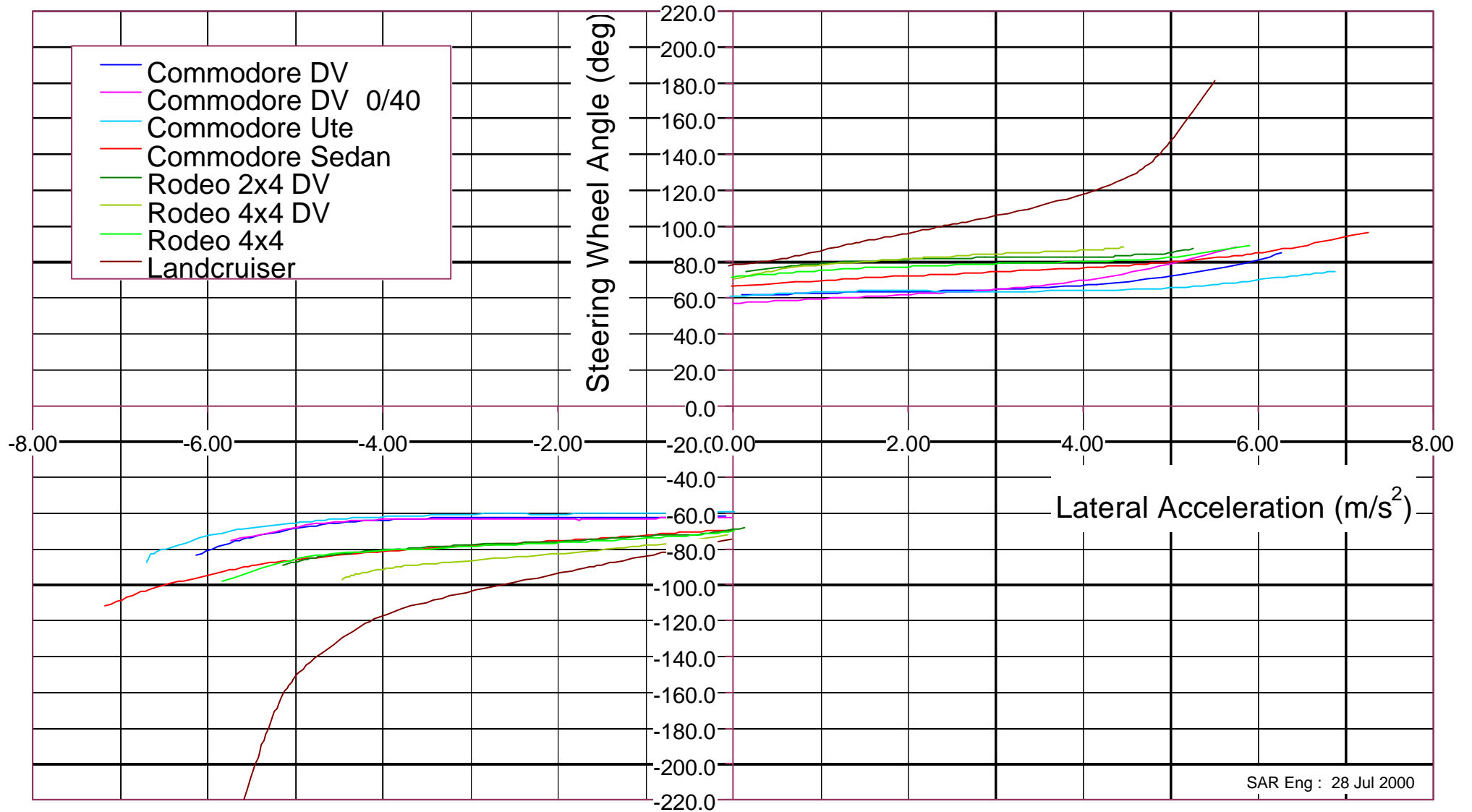
The upper right quadrant of the plot illustrates the difference between the Commodore divisional van 0/40 and the 40/40. The 0/40 has a higher linear gradient and an earlier knee, from a handling perspective the upper right 0/40 curve is better than the 40/40.

The divergence of the Commodore divisional van and Commodore divisional van 0/40 rear air bag pressures indicates a 10% difference in steady state handling performance between left and right turns at 0.7 of the limit of lateral acceleration.

The Landcruiser difference is due to a lower steering ratio and illustrates a good linear range with a definite change (knee) at 0.5 of the limit of lateral acceleration. All of the remaining vehicles are starting to illustrate the knee at the 0.7 limit of lateral acceleration.

Figure 6 Results of the steady state turning tests for the police vehicles

STEADY STATE TURNING TESTS FOR VICTORIAN POLICE VEHICLES



SAR Eng : 28 Jul 2000

3.4.2 Double Lane Change Manoeuvre

Double Lane Change Manoeuvre Tests were conducted using a stretched version of the Consumers Union obstacle avoidance course. The test was conducted on a dry concrete surface. The aim of the test was to assess the handling performance while executing an emergency manoeuvre.

Unlike the other tests that are open-loop, the lane change manoeuvre is a closed-loop test where the driver's control abilities are necessary for the course to be negotiated satisfactorily. Rather than using the driver's subjective comments to rate vehicle performance, performance was assessed by a series of metrics calculated during the manoeuvre. The majority of the metrics are based on those proposed in SAE Paper 780010 "Correlation and Evaluation of Driver/Vehicle Directional Handling Data".

Metrics calculated included:

- Entry speed to the course
- Peak lateral accelerations.

During the Double Lane Change manoeuvre the following data was collected; velocity through the test, and maximum and minimum lateral acceleration. Testing was conducted manoeuvring to both the left and right. The testing nominally started at a velocity of 15ms^{-1} , or a speed of 54km/h, the velocity was increased until a peak lateral acceleration of 0.7 of the rollover lateral acceleration was achieved or the vehicle could not negotiate the course.

During the testing all vehicles successfully negotiated the lane change manoeuvre. The test was then repeated twice more to provide three data sets, the process was then repeated for opposite manoeuvre (see App. 2, Figure 11 & Figure 12).

From each test run the velocity, maximum and minimum lateral acceleration were obtained and the delta acceleration (difference between maximum and minimum) was determined. The Double Lane Change Manoeuvre graph Figure 7, plots the above parameters and compares Lateral Accelerations to velocity.

The key interpretations of the graph are; that the trend lines are similar in shape and gradient and that the ranking profile of the Mengert Study is followed. The exception is the Landcruiser, which ranks second best and performed significantly better than expected by the Mengert profile. The handling difference between the Commodore divisional van and Commodore divisional van 0/40 rear air bags is also illustrated.

The Commodore divisional van 0/40 has different handling than the 40/40. A 0/40 vehicle will have at least a 15% difference in how the vehicle handles left to right. This would provide confusing feed back to the driver and require different steering inputs.

It should also be noted that the 0 turn of the 0/40 enables the vehicle to manoeuvre through the double lane change at a higher velocity for a given lateral acceleration than the 40/40.

Based on the Steady State and Double Lane Change Manoeuvre, consideration should be given to reducing the air pressure in the rear suspension air bags to zero. This would eliminate both the ongoing maintenance issue and the need to link the left and right air bags. The consequence would be more body roll, possibly causing the operators to reduce their speed. The operators most likely will disapprove of such a modification as they would be able to feel the increase in body roll and think that the vehicle is more likely to rollover.

DOUBLE LANE CHANGE MANOEUVRE FOR VICTORIAN POLICE

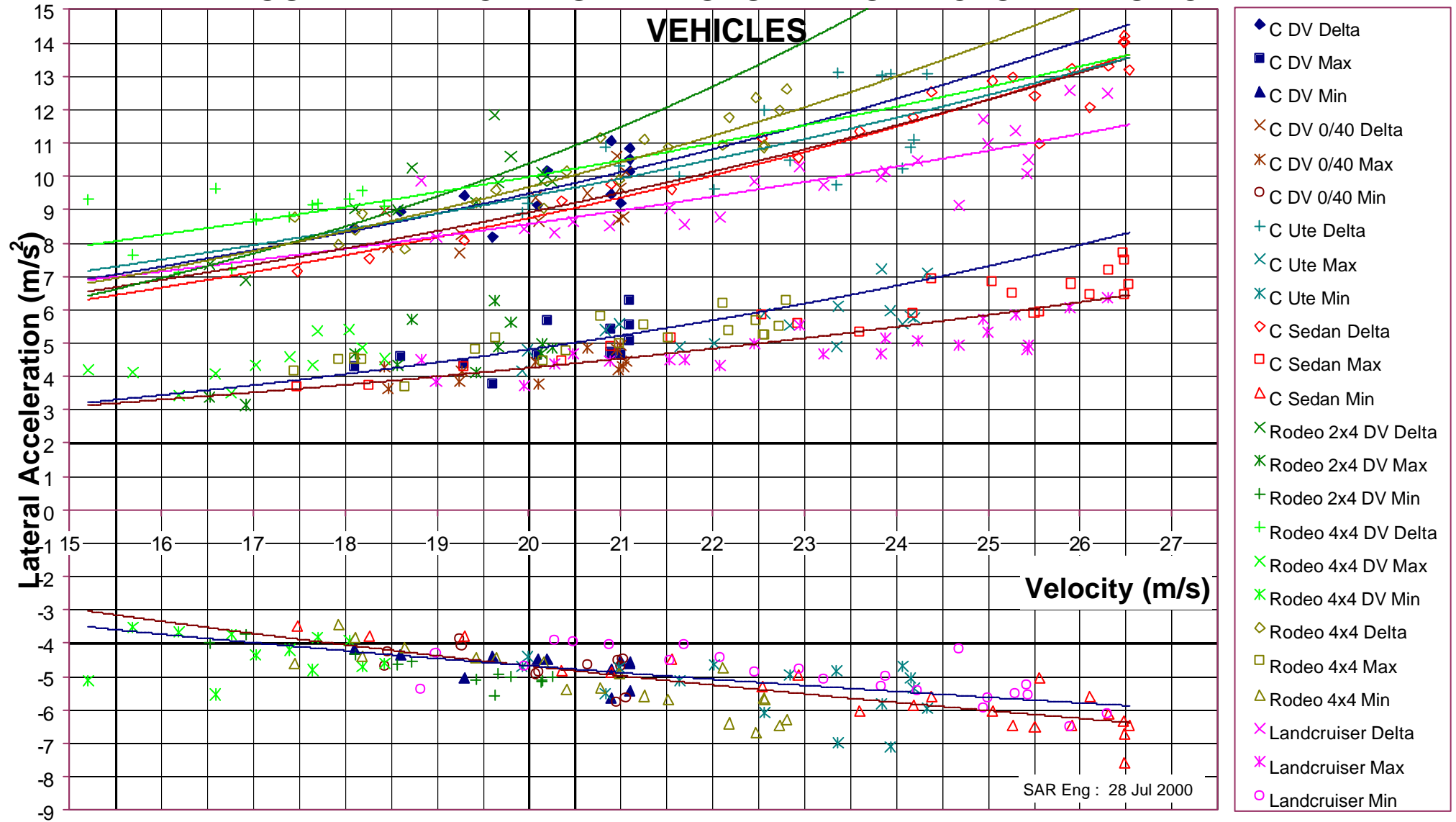


Figure 7 Results of tests for Double Lane Change Manoeuvre

4. SUMMARY OF FINDINGS

4.1 Rollover Crash Rate for Police Vehicles

Analysis of the police vehicle accident database (for the period 1990 to June 2000), identified the number of rollovers that different model types were involved in. The highest figures were: 11 for Commodore divisional vans; 5 for Holden Rodeo divisional vans (4x2); and 7 for Toyota Landcruiser models. This compares with 2 'rollover' involved crashes identified for the previous Ford divisional van, and 2 for each of the Commodore and Ford sedans.

Based on the exposure measure 'vehicle-months', the lowest rollover rate is for the Commodore sedan (**0.25** rollovers per 10,000 vehicle months), with the highest calculated for the Rodeo 4x2 (**52**). For the Holden divisional van the rate of **16.6** compares with the much lower rate of **0.95** calculated for the previous Ford Falcon divisional van, a relative rate of 17 to 1.

Based on kilometres travelled, the Commodore and Ford sedans have a low rate of less than **0.24** rollovers per 10 million kms travelled; the Ford Divvy van has a similar value of **0.20**. The Commodore divisional van has a significantly higher rate of **3.26**, with the Toyota Landcruiser models varying from **3.46 to 6.1**). The highest rate is for the Rodeo 4x2, which is **18.5**.

A reservation regarding the data analysis is that the police vehicle accident database does not explicitly categorise the vehicle crash type, and that the type of crash had to be identified from reference in any accident description to the vehicle having "rolled"⁷.

4.2 Vehicle Stability

The following Table 7 summarises the rollover rates and Mengert study 'risk of rollover' for the various vehicles. A comparison of these various measures highlights the consistency between the actual relatively high rollover rates and Mengert stability results found for the Holden divisional van, Rodeo 4X2, and Landcruiser.

Taking the relatively high rollover crash rate for the **Commodore divisional van**, together with its ranking in the Mengert rollover risk plots, Steady State Turning Test and the Double Lane Change manoeuvre, indicates that the rollover 'problem' is predominantly related to the height of the vehicle's center of gravity and not the suspension set-up or handling of the vehicle.

⁷ Cases where a vehicle had 'rolled' due to the parking brake being left off or through other factors, were of course excluded.

Vehicle Description	No. of Identified Rollovers	Sum Of Vehicle - Months	Sum of Kilometres Travelled (millions kms)	Rollover Rate per 10,000 Vehicle-Months	Rollover Rate per 10 million kms	Mengert Study – % Rollover Risk
RODEO 4X2	5	968	2.7	51.6	18.5	69
L/CRUISER HARDTOP LWB	3	2835	4.9	10.6	6.1	68
LANDCRUISER WAGON 105R	1	4310	1.8	2.3	5.6	44
L/CRUISER WAGON 80R	3	4517	8.7	6.6	3.5	(44?)
HOLDEN DIVVY VAN	11	6842	33.7	16.6	3.26	37
JACKAROO WAGON	1	1619	5.2	6.2	1.9	-
PATROL WAGON	1	3673	8.3	2.7	1.2	-
FORD FALCON SEDAN	5	83526	98.7	0.60	0.24	-
FORD FALCON DIVVY VAN	2	21003	206.9	0.95	0.20	18
COMMODORE SEDAN	2	81021	248..8	0.25	0.08	6
TOTALs	34					

Table 7 Summary of rollover rates for the police vehicles, and rollover risk from Mengert study.

From the results of the Tilt Table tests for rollover stability, the Mengert Study graph plots for the 13 vehicles tested (Figure 4), indicate that the Holden Commodore divisional van has a ‘probability of being involved in a rollover’ of about double that of the old Falcon divisional van (38% vs 18%), and double that of the Commodore ute from which it is derived. The Rodeo divisional vans have a very high rating of nearly 70%, indicating quite adverse rollover stability characteristics. The significantly increased rollover risk for the modified divisional van version of both the Commodore and Rodeo is clearly seen from this graph and the Tilt Table results.

In regard to the stability and handling of the Commodore divisional van, it is relevant to note from a driver’s perspective that though the divisional van’s cabin is similar to that of the Commodore sedan, its rollover stability and handling are considerably reduced.

A factor also identified as having some effect on the Commodore’s stability is the variation in the rear airbag suspension pressures. These were found to vary from 0 to 60 psi, for a sample of vehicles tested. The design pressure is 40 psi for both sides.

The relatively high rollover rate, and low (adverse) stability ranking for the **Rodeo (4x2) divisional van**, would clearly identify this vehicle as having a high risk of being involved in a rollover crash.

The rollover rate for the **Toyota Landcruiser** models also suggests that a review into the type of use of this vehicle may be appropriate, with the aim of reducing rollovers.

4.3 Some Options to Reduce the Centre of Gravity Height for the Current Holden Commodore Divisional Van

The stability of the Holden VS Commodore divisional van could be improved by lowering the CG height. The following options are presented as potential ways to achieve this, and to illustrate their effects in terms of improved rollover stability through reduction in CG height. Implementation of any of these Options would clearly require further detailed evaluation.

Option 1: Lowering the suspension of the Commodore divisional van. This could be done by removing 50mm of the compressed spring length, by either replacing the springs with shorter ones or removing the current springs and machining off a defined length. A 50mm reduction will reduce the probability of a rollover from 39% to 30% (see App. 1, Figure 10)

Option 2. Reducing the mass of the divisional van pod. Based on the measurements taken by AEA the pod weighs⁸ 340kg. Although it is considered viable to remove some mass, the engineering design effort required to validate the mass removal could be onerous. If 50kg were removed, the rollover probability would be reduced from 39% to 34% (App. 1, Figure 9). If 100kg were able to be removed, the rollover probability would be reduced from 39% to 31%. For 150kg removed (which would require considerable effort, analysis and optimisation) the rollover probability would be reduced from 39% to 28%. For a 200kg reduction in mass (which would require new design and manufacture), the rollover probability would be reduced from 39% to 25%.

Option 3: Lowering the suspension by 50mm and reducing the divisional van pod mass (App. 1, Figure 10). Lowering the suspension and removing 50kg would reduce the probability of a rollover from 39% to 24%. Lowered suspension and 100kg removed would reduce the probability of a rollover from 39% to 21%. Lowered suspension and 150kg removed would reduce the probability of a rollover from 39% to 18%. Lowered suspension and 200kg removed would reduce the probability of a rollover from 39% to 16%, which is around the value for the old Falcon divisional van.

⁸ The breakdown of the pod mass is not accurately known.

5. CONCLUSIONS

The analysis of the limited police vehicle accident data available identified that from 1990, 39 crashes involved rollover. Of these, 11 involved Holden Commodore divisional vans; 7 involved Toyota Landcruiser models, and 5 involved Rodeo 4x2 divisional vans.

Based on the exposure measure 'vehicle-months', and kilometres traveled, these vehicles have a significantly⁹ higher rollover rate than either the Commodore and Falcon Sedans or the previous Ford Falcon divisional van, with the Toyota Landcruiser and Holden Rodeo divisional vans being higher still.

Applying the Tilt Table stability tests results (13 vehicles tested) to the Mengert study¹⁰ showed that the increased mass of the prisoner pods added to the base Commodore ute and Rodeo vehicles, doubled¹¹ the 'rollover risk'.

The dynamic handling tests (6 vehicles tested) comprising steady state turning and double lane change manoeuvres, showed that the relative handling performance of the vehicles, (except for the Toyota Landcruiser, which was better) followed that found in the Tilt Table stability tests. These results provide confirmation that the increased rollover risk for the Commodore divisional van related to its increased Centre of Gravity height rather than any inherent handling deficiency's of the base vehicle. Also identified, though of lesser influence was the significant variation in measured airbag pressures for the rear suspension of the Commodore divisional vans.

For the Commodore divisional van, reductions in spring height of 50mm combined with a 150kg mass reduction would be needed to reduce the 'rollover risk' from 38% to 18%, consistent with that of the previous Ford divisional van. The practicality of such changes to existing VS Commodore Divvy vans may be doubtful and would need detailed investigation.

Although the Commodore utility fitted with the prisoner pod has very similar cabin layout and driver controls as the Commodore sedan, the handling and rollover stability characteristics are very different between the two vehicles. This apparent similarity could result in giving drivers false perceptions as regards the performance expectations for the Commodore Divisional van. That is, the actual performance characteristics of the Commodore Divisional van do not appear to be congruent with the expected task demands as a first response vehicle, nor of a vehicle which is based on a sedan style model.

⁹ Refer Chi-Square Goodness-of-Fit Test in Appendix 4.

¹⁰ The Mengert study relates the probability of a vehicle type being involved in a rollover to its stability factor.

¹¹ It is noted that whereas the rollover rate for the Commodore divisional van was found to be some 16 times that of the previous Falcon Divvy van, the Mengert study indicates that the Commodore divisional van has about twice the 'risk of being involved in a rollover'. This apparent contradiction can be explained in the main by noting that the Mengert study provides an estimate of 'the **risk** of a vehicle type being involved in a rollover, not a rollover **rate**. The actual rollover rate experienced by a vehicle is a function of a vehicle's stability characteristics *as well as* other factors (usage, environment, driver training, policy etc).

6. RECOMMENDATIONS

1. Review and upgrade the police vehicle accident database, to include crash type and other variables relating to crash type, circumstances, and severity and injury outcome. Such data is important in providing feedback on vehicle performance and possible problems, thus providing information for rectification or upgrade.
2. Investigate the type of usage of the Toyota Landcruiser to identify ways to reduce rollover risk.
3. Consider Changes to the VS Commodore divisional van to reduce rollover and injury risk, including:
 - Link the left and right rear suspension air bags, provide a pressure gauge so that the operators can see if the bags are flat. Provide training for the operators on the importance of the checking tyre and air bag pressures.
 - Examine feasibility of reducing the suspension height of the Commodore divisional van Suspension by 50mm.
 - Conduct an engineering assessment on the feasibility to reduce the mass of the Commodore divisional van pod.
 - Evaluate the extending the ROPS to protect the front two occupants
 - Consider fitting additional sash belt to protect front seat occupants in a rollover
4. Consider fitting an accident data recorder to vehicles to enable reconstruction of major crashes (and hence better determine crash severity parameters), and as a possible deterrent to 'brash' driving behaviour.

The detailed study and review of the functional and performance requirements for police vehicles will be considered as part of the Phase 2 Project.

7. REFERENCES

Report LM4615, Determination of Overturn Angle and Centre of Gravity of Victoria Police Vehicles, Army Engineering Agency, Mechanical Laboratory. Maribyrnong, Victoria.

Report LM4626, Determination of Overturn Angle and Centre of Gravity of Victoria Police Vehicles, 26th June 2000; Army Engineering Agency, Mechanical Laboratory, Maribyrnong, Victoria.

Mengert P, Salvatore S, DiSario R. and Walter R., "Statistical Estimation of Rollover Risk" Aug 1989, DOT-TSC-NHTSA-89-3

APPENDIX 1

Effect of mass change and lowering springs on stability of Holden Commodore divisional van

(Mengert
Figure 8, Figure 9, Figure 10)

Plots

-

Lowering the suspension of the Commodore Divisional Van by 50mm

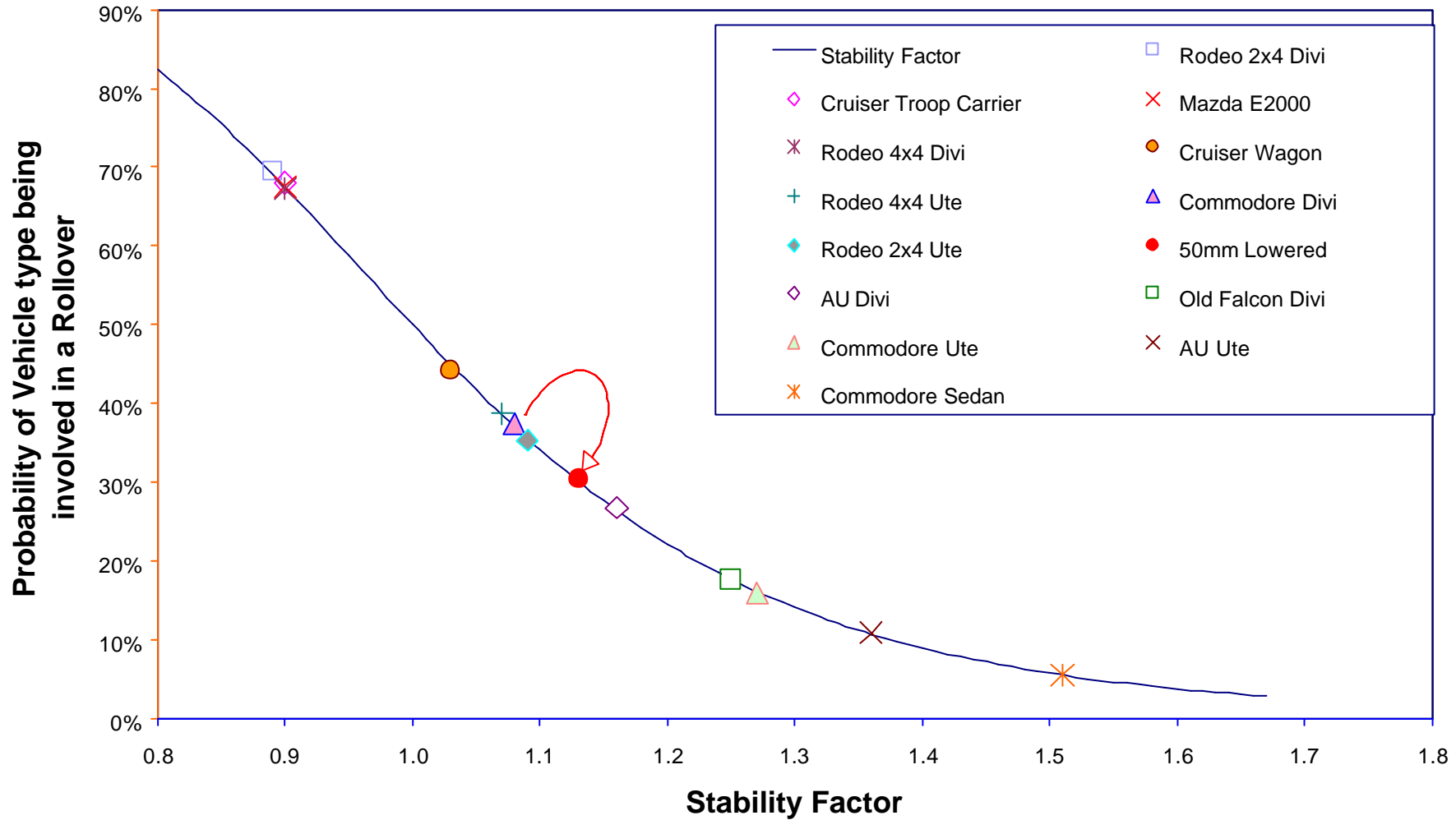


Figure 8 Menger Stability Plot – effect of reducing mass and lowering suspension level for the Commodore divisional van

Reducing the mass of the Commodore DV Pod by increments of 50kg

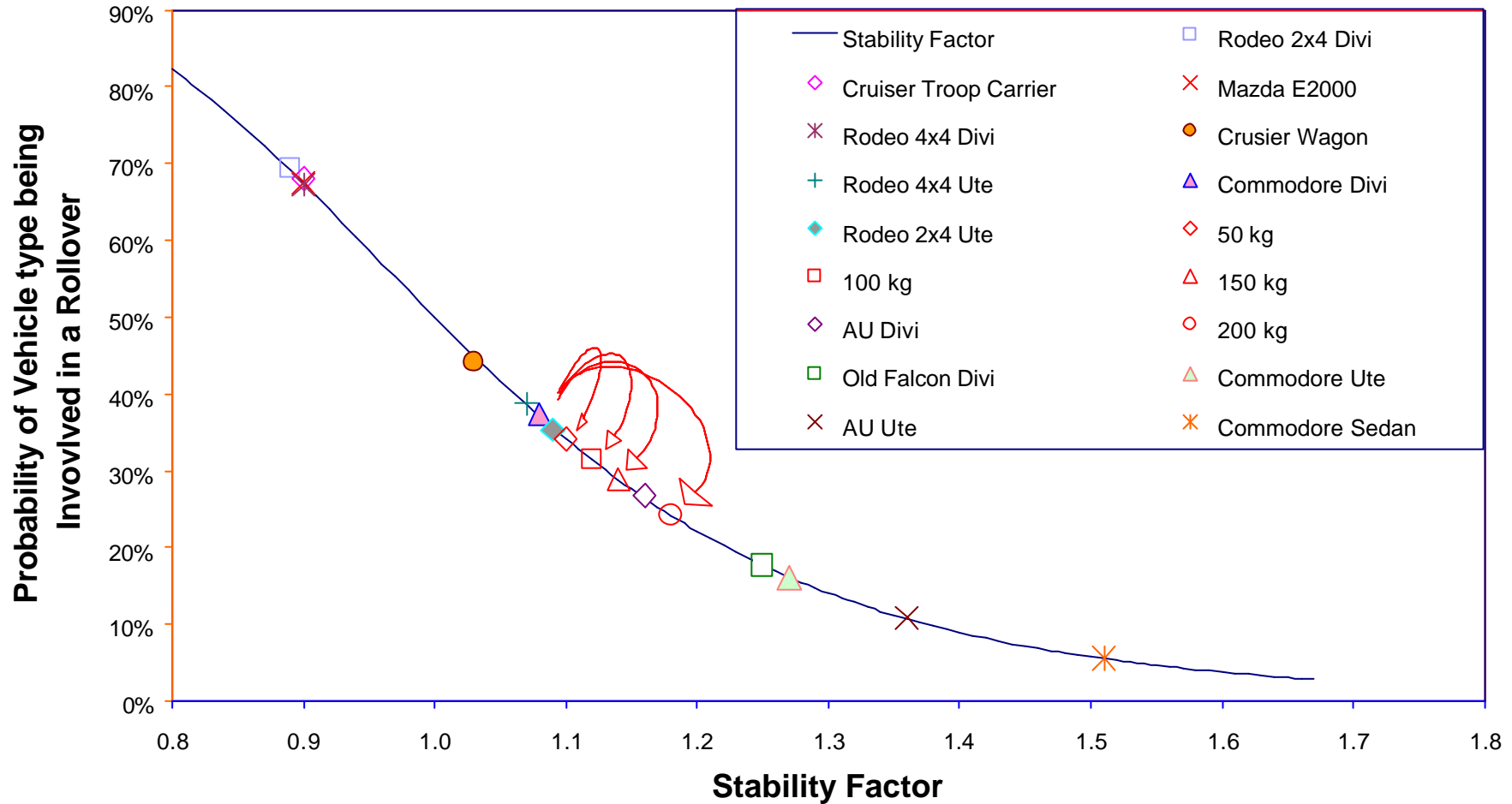


Figure 9 Menger Stability Plot – effect of reducing mass for the Commodore divisional van

Lowering the suspension of the Commodore Divisional Van by 50mm

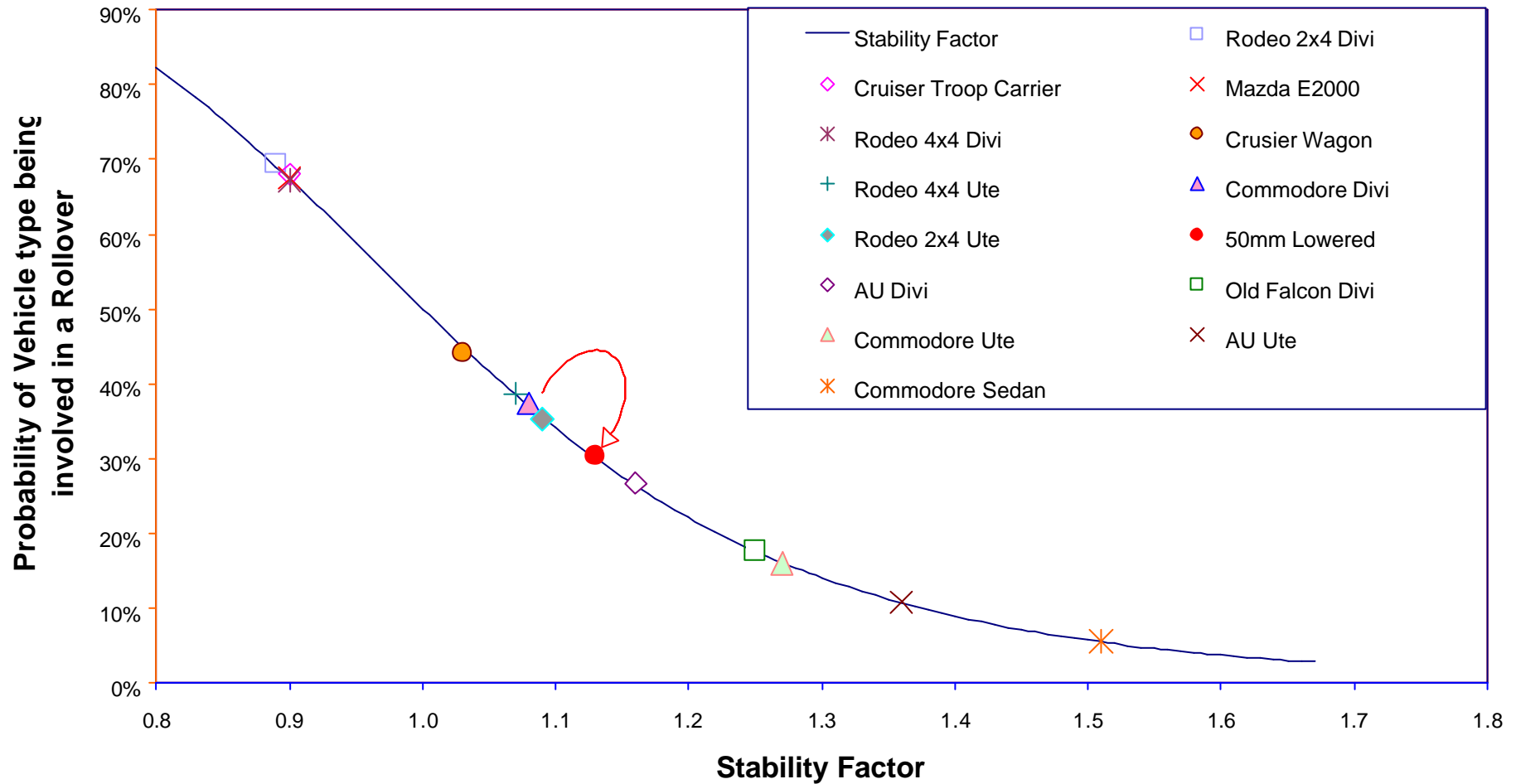


Figure 10 Menger Stability Plot – effect of lowering the suspension for the Commodore divisional van

APPENDIX 2

Example of Results Plot of Double Lane Change Manoeuvre

(Figure 11, Figure 12)

DOUBLE LANE CHANGE MAZ 383
Left and Right Manoeuvre

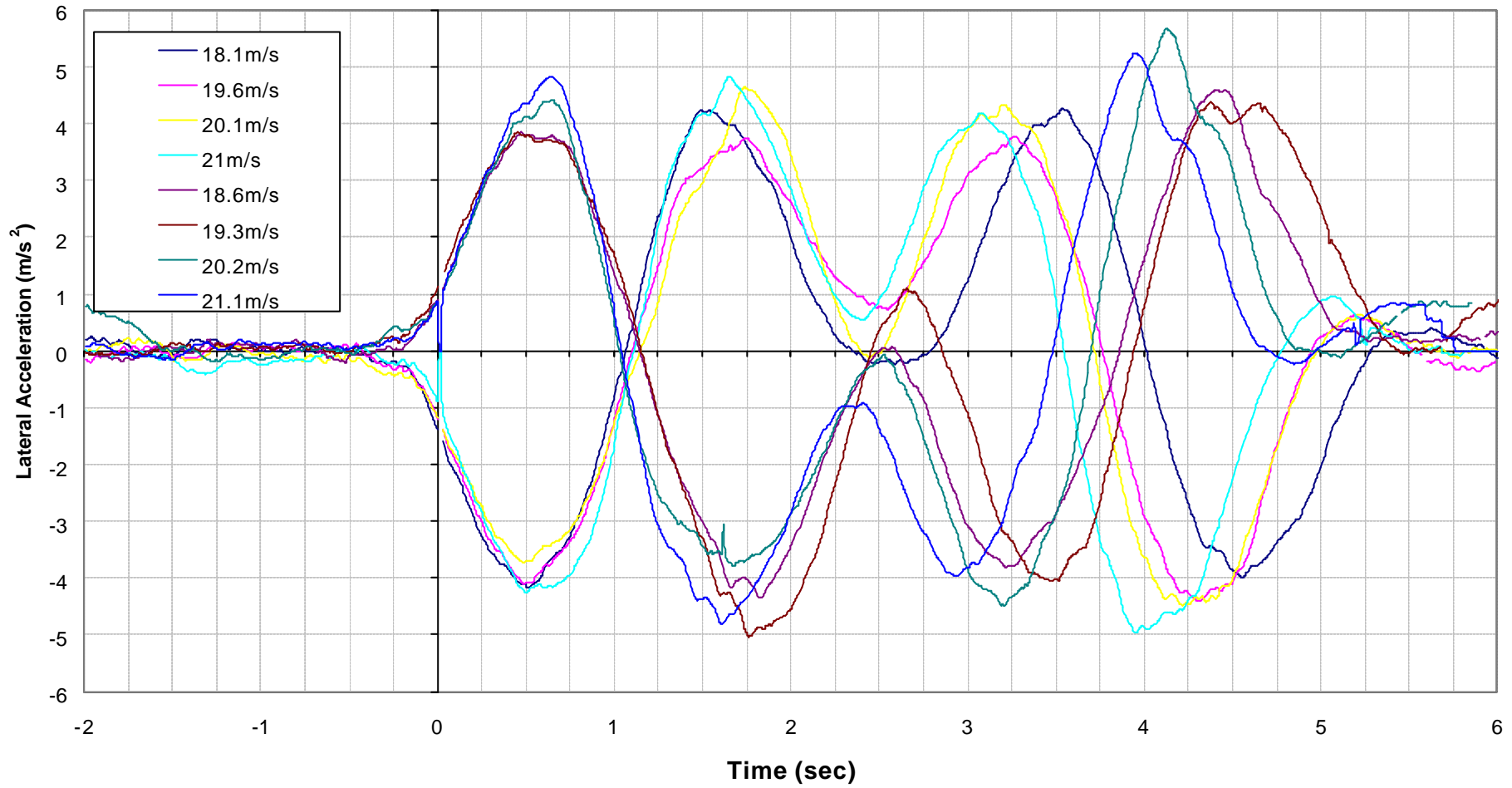


Figure 11 Result for vehicle test for double lane change manoeuvre, turning left and turning right

DOUBLE LANE CHANGE MANOEUVRE (LEFT)

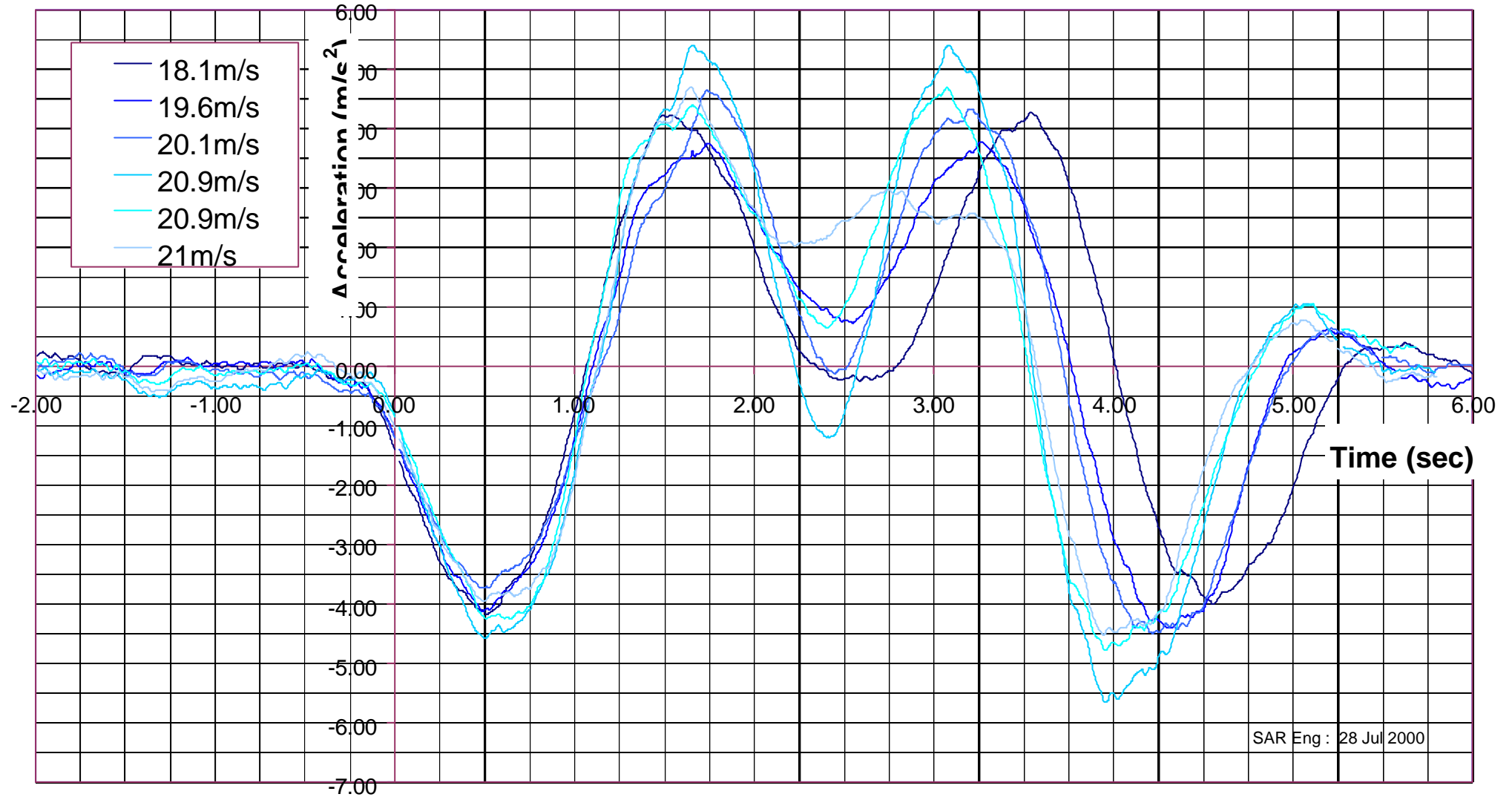


Figure 12 Result for vehicle test for double lane change manoeuvre, turning left

APPENDIX 3

Police Vehicle model database: model descriptions and groupings

(refer Section 3.1 & 3.2)

VEHICLE DESCRIPTIONS

COMMODORE SEDAN

ACCLAIM VR 3.8 AUTO SEDAN
ACCLAIM VS 3.8 AUTO SEDAN
ACCLAIM VS1 3.8L AUTO SEDAN
ACCLAIM VS2 3.8L AUTO SEDAN
ACCLAIM VT1 3.8MPI AUTO SEDAN
ACCLAIM VTII 3.8MPI AUTO SEDAN
BERLINA 3.8 AUTO SEDAN
BERLINA 3.8 VP AUTO SEDAN
BERLINA GEN.3 5.7MPI AUTO SEDAN
BERLINA VS 3.8 AUTO SEDAN
BERLINA VS1 3.8L AUTO SEDAN
BERLINA VS2 3.8MPI AUTO SEDAN
BERLINA VS2 5.0MPI AUTO SEDAN
BERLINA VT1 3.8MPI AUTO SEDAN
BERLINA VT1 5.0MPI AUTO SEDAN
BERLINA VTII 3.8MPI AUTO SEDAN
CALAIS 3.8 VN AUTO SEDAN
CALAIS 3.8 VP AUTO SEDAN
CALAIS VS2 3.8 S/C AUTO SEDAN
CALAIS VS2 5.0MPI AUTO SEDAN
CALAIS VT1 3.8 S/C AUTO SEDAN
CALAIS VT1 3.8MPI AUTO SEDAN
CALAIS VT1 5.0MPI AUTO SEDAN
CALAIS VTII 3.8MPI AUTO SEDAN
COMMODORE EXEC 3.8LPG AUTO SEDAN
COMMODORE EXEC VN 3.8 AUTO SEDAN
COMMODORE EXEC VN 3.8 MAN SED
COMMODORE EXEC VN 5.0 AUTO SED
COMMODORE EXEC VP 3.8 AUTO SED
COMMODORE EXEC VP 3.8LPG AUTO SED
COMMODORE EXEC VP 5.0 AUTO SED
COMMODORE EXEC VP 5.0 MANUAL SEDAN
COMMODORE EXEC VR 3.8 AUTO SED
COMMODORE EXEC VR 3.8 MAN SEDAN
COMMODORE EXEC VR 3.8LPG AUTO SED
COMMODORE EXEC VR 5.0 AUTO SED
COMMODORE EXEC VR 5.0 MANUAL SED

COMMODORE EXEC VR1 3.8 AUT SED
COMMODORE EXEC VS 3.8 AUTO SED
COMMODORE EXEC VS 5.0 AUTO SED
COMMODORE EXEC VS 5.0 MANUAL S
COMMODORE EXEC VS1 3.8 AUT SED
COMMODORE EXEC VS1 3.8 MAN SED
COMMODORE EXEC VS1 5.0 AUT SED
COMMODORE EXEC VS1 5.0 MAN SED
COMMODORE EXEC VS2 3.8 AUT SED
COMMODORE EXEC VS2 5.0 AUT SED
COMMODORE EXEC VS2 5.0 MAN SED
COMMODORE EXEC VT1 3.8 AUT SED
COMMODORE EXEC VT1 5.0 AUT SED
COMMODORE EXEC VT1 5.0 MAN SED
COMMODORE EXEC VTII 3.8 AUTO SEDAN
COMMODORE GEN.3 SS 5.7 AUTO SEDAN
COMMODORE GEN.3 SS 5.7 MANUAL SEDAN
COMMODORE S S/C VT 3.8 AUTO SEDAN
COMMODORE S VS2 3.8 AUTO SEDAN
COMMODORE S VT1 3.8 AUTO SEDAN
COMMODORE S VTII 3.8 AUTO SEDAN
COMMODORE S VTII 3.8 MANUAL SEDAN
COMMODORE S VTII S/CHARGER 3.8 AUTO SEDAN
COMMODORE SS 5.0 AUTO/SED
COMMODORE SS S/C VT 3.8 AUT SEDAN
COMMODORE SS VS 5.0 AUTO SED
COMMODORE SS VS 5.0 MANUAL SED
COMMODORE SS VS1 5.0 AUT SEDAN
COMMODORE SS VS1 5.0 MAN SEDAN
COMMODORE SS VS2 5.0 AUT SEDAN
COMMODORE SS VS2 5.0 MAN SEDAN
COMMODORE SS VT1 5.0 AUT SEDAN
COMMODORE SS VT1 5.0 MAN SEDAN

STATESMAN WH 3.8MPI AUTO SEDAN

HOLDEN ASTRA GL 1.8L AUTO SEDAN

HOLDEN NOVA

HOLDEN NOVA GS 1.8 5SP MAN SED
HOLDEN NOVA GS 1.8 MAN HATCH

FORD FALCON SEDAN

FAIRMONT 4.1L AUTO/SED
FAIRMONT AU1 4.0MPI AUTO SEDAN
FAIRMONT AU2 4.0MPI AUTO SEDAN
FAIRMONT AU2 5.0MPI AUTO SEDAN
FAIRMONT EB 3.9MP AUTO SEDAN
FAIRMONT EB2 4.0LPG AUTO SED
FAIRMONT EB2 4.0MPI AUTO SED
FAIRMONT ED1 4.0MPI AUTO SED
FAIRMONT EF1 4.0MPI AUTO SEDAN
FAIRMONT EF2 4.0MPI AUTO SEDAN
FAIRMONT EF2 5.0MPI AUTO SEDAN
FAIRMONT EL1 4.0MPI AUTO SEDAN
FAIRMONT EL1 5.0MPI AUTO SEDAN
FAIRMONT GHIA 4.0MPI AUT SEDAN
FAIRMONT GHIA 4.0MPI AUTO SEDAN
FAIRMONT GHIA 5.0MP AUT SEDAN
FAIRMONT GHIA EB 5.0 AUTO/SED.
FALCON FORTE AU1 4.0MPI AUTO SEDAN
FALCON FORTE AU2 4.0MPI AUTO SEDAN
FALCON GL 3.9MPI AUTO SEDAN
FALCON GL 3.9MPI MAN/SED
FALCON GL 4.1L AUTO SEDAN
FALCON GL EB 3.9 AUTOMATIC SED
FALCON GL EB 3.9LPG AUTO SED
FALCON GL EB 3.9MP AUTO SEDAN
FALCON GL MP 30.ANN T/BAR SED
FALCON GL T/BAR LPG EA1 SEDAN
FALCON GL T/BAR SEDAN
FALCON GLI EB2 4.0LPG AUTO SED
FALCON GLI EB2 4.0MP AUTO SED
FALCON GLI ED1 4.0LPG AUTO SED
FALCON GLI ED1 4.0MP AUTO SED
FALCON GLI ED1 5.0MP MANUAL SEDAN
FALCON GLI EF1 4.0MP AUT SEDAN
FALCON GLI EF2 4.0MP AUT SEDAN
FALCON GLI EF2 5.0MP AUT SEDAN
FALCON GLI EL1 4.0MPI AUT SED
FALCON S 3.9EFI EA AUTO SEDAN
FALCON S 3.9MPI AUTO/SED
FALCON S EB 3.9MP AUTO SEDAN

FALCON S XR8 5.0 EBII AUTO SED
FALCON XR6 4.0 AU AUTO SEDAN
FALCON XR6 4.0 ED AUTO SED
FALCON XR6 4.0 EF AUTO SED
FALCON XR6 4.0 EF MANUAL SEDAN
FALCON XR6 4.0 EL AUTO SEDAN
FALCON XR6 4.0 EL MANUAL SEDAN
FALCON XR8 5.0 AU AUTO SEDAN
FALCON XR8 5.0 ED AUTO SED
FALCON XR8 5.0 EF AUTO SEDAN
FALCON XR8 5.0 EF MANUAL SEDAN
FALCON XR8 5.0 EL AUTO SEDAN
FALCON XR8 5.0 EL MANUAL SEDAN
FUTURA AU1 4.0MPI AUTO SEDAN
FUTURA ED1 4.0MP AUTO SED
FUTURA EF1 4.0MP AUTO SEDAN
FUTURA EF2 4.0MP AUTO SEDAN
FUTURA EL1 4.0MPI AUTO SEDAN

FORD FAIRLANE SEDAN

FAIRLANE GHIA 3.9 AUTO SALOON
FAIRLANE GHIA 4.0 AUTO SEDAN
FAIRLANE GHIA 5.0 AUTO SEDAN
FAIRLANE GHIA NL 5.0 AUTO SEDAN
FAIRLANE NA SERIES AUTO/SEDAN
FAIRLANE ZL SERIES AUTO/SEDAN

FESTIVA GLI 13EFI 5SP MAN HATCH

FORD LASER GLXi 1.8MPI MAN HATCH

CAMRY TOURING 3.0 V6 MANUAL SEDAN

GALANT HATCH

GALANT V6-24 5 DR HATCH AUTO
GALANT V6-24 5 DR HATCH MANUAL

CHALLENGER V6 30MPI 4X4 MAN VAGON

DISCOVERY

DISCOVERY 4X4 3.5 SAFETY RESCUE UNIT
DISCOVERY 4X4 3.9L 5DR WAGON AUTO
DISCOVERY ES 4X4 V8 4.0MPI AUTO WAGON

EXPLORER XLT 4X4 4.0EFI AUTO WAGON**HILUX**

HILUX D/CAB 2.4 4X4 MAN P/UP
HILUX D/CAB 2.7 PICKUP MANUAL
HILUX D/CAB 3.0D 4X4 MAN UTE
HILUX D/CAB P/UP 2.4L AUTO
HILUX D/CAB P/UP 2.4L MANUAL
HILUX D/CAB PICKUP 2.4 DSL MAN
HILUX D/CAB UTE 2.8D 4X4 MANUAL
HILUX DX D/CAB PICKUP 2.4 AUTO
HILUX DX D/CAB PICKUP MANUAL

HILUX UTE

HILUX D/CAB 2.4 4X4 MAN P/UP
HILUX D/CAB 2.7 PICKUP MANUAL
HILUX D/CAB 3.0D 4X4 MAN UTE
HILUX D/CAB P/UP 2.4L AUTO
HILUX D/CAB P/UP 2.4L MANUAL
HILUX D/CAB PICKUP 2.4 DSL MAN
HILUX D/CAB UTE 2.8D 4X4 MANUAL
HILUX DX D/CAB PICKUP 2.4 AUTO
HILUX DX D/CAB PICKUP MANUAL

LANDCRUISER SW

L/CRUISER 4.0L MANUAL WAGON
L/CRUISER 4.5 EFI RV MAN WAGON
L/CRUISER 42DSL 4X4 MAN WAG HZJ105R
L/CRUISER 42DSL 4X4 MAN WAG HZJ80R
L/CRUISER 4X4 4.5 RV MAN WAGON

FORD FALCON UTES

FALCON GL UTE 4.1L AUTO
FALCON GLI UTE 4.0L T/BAR AUTO
FALCON S UTE 4.0L T/BAR AUTO

FALCON S" XH2 5.0MPI T/AUTO UTE"
FALCON XG1 4.0L T/BAR AUTO UTE
FALCON XH S 4.0L T/BAR AUT UTE
FALCON XH1 4.0L T/BAR AUTO UTE
FALCON XH2 4.0L T/BAR AUTO UTE
FALCON XL 4.0MPI AU11 T/AUTO UTILITY
FALCON XLS 4.0MPI T/AUTO UTE
FALCON XLS 5.0MPI MANUAL UTE
FALCON XR6 4.0 AU1 MANUAL UTE
FALCON XR6 4.0 AU1 T/AUTO UTE
FALCON XR8 5.0 AU T/AUTO UTE

FORD FALCON DIVVY VANS

FALCON GL VAN 4.1L COL AUTO.
FALCON GLI VAN 4.0L COL AUTO
FALCON GLI VAN 4.0L T/BAR AUTO
FALCON XG1 4.0L COL AUTO P/VAN
FALCON XH1 4.0L COL AUTO P/VAN
FALCON XH1 4.0L T/B AUTO P/VAN
FALCON XH2 4.0L COL AUTO P/VAN
FALCON XH2 4.0MPI T/AUTO P/VAN

FORESTER WAGON

FORESTER GT 20MPI 4WD 5SP MAN WAGON
FORESTER GT 20MPI 4WD AUTO WAGON
FORESTER RX LTD 20 AUTO 4WD WAGON

HOLDEN UTE

HOLDEN S UTE 3.8L AUTO FLOOR
HOLDEN S UTE VP3.8L AUTO FLR
HOLDEN S UTE VS3.8L T/B AUTO
HOLDEN S VS2 3.8 T/B AUT UTE
HOLDEN S VS3 3.8 T/B AUTO UTE
HOLDEN S UTE VR3.8L T-B AUTO
HOLDEN S VS3 5.0MPI MANUAL UTE
HOLDEN UTE VR 3.8L T/BAR AUTO
HOLDEN UTE VS 3.8L T/BAR AUTO

HOLDEN DIVVY VANS

HOLDEN UTE VR 3.8L COLUMN AUTO
HOLDEN UTE VS 3.8L COLUMN AUTO
HOLDEN UTE VS2 3.8L COLUM AUTO
HOLDEN VS1 3.8L COL AUTO UTE
HOLDEN VS2 3.8L COL AUTO UTE
HOLDEN VS3 3.8L COL AUTO UTE

JACKAROO WAGON

JACKAROO 4X4 3.1DSL TURBO/MAN WAGON
JACKAROO 4X4 SE V6 3.2MPI AUTO WAG
JACKAROO 4X4 SE V6 3.2MPI MAN WAG
JACKAROO 4X4 V6 3.2MPI 5SP MAN WAG
JACKAROO MONTEREY V6 3.5 4X4 AUTO WAGON
JACKAROO SE V6 3.5 4X4 AUTO WAGON
JACKAROO SE V6 3.5 4X4 MAN WAGON

JEEP CHEROKEE SPORT 40 4X4 AUTO WAGON**L/CRUISER WAGON**

L/CRUISER 4.0L MANUAL WAGON
L/CRUISER 4.5 EFI RV MAN WAGON
L/CRUISER 42DSL 4X4 MAN WAG HZJ105R
L/CRUISER 42DSL 4X4 MAN WAG HZJ80R
L/CRUISER 4X4 4.5 RV MAN WAGON
L/CRUISER GXL 4.0L AUTO WAGON
L/CRUISER GXL 4X4 4.5EFI AUTO WAGON
L/CRUISER GXL 4X4 4.5MPI MAN WAGON

L/CRUISER HARDTOP

L/CRUISER 4X4 FZJ75 LWB4.5 6ST MAN
L/CRUISER 4X4 HJ75 LWB 3S 4.0L MAN
L/CRUISER 4X4 HJ75 LWB4.2D 3ST MAN
L/CRUISER 4X4 HJ75 LWB4.2D 6ST MAN
L/CRUISER 4X4 HJ75 LWB4.5L 6ST MAN
L/CRUISER 4X4 HZJ75 LWB4.2D 6ST MAN
L/CRUISER 4X4 HZJ75RV 4.2D 11S MAN
L/CRUISER 4X4 HZJ75RV 4.2D 6ST MAN
L/CRUISER 4X4 HZJ78RV LWB4.2D 6ST MAN
L/CRUISER FRP TOP LSD 4.0 MAN
L/CRUISER H/T LWB 4.0L 6ST MAN

L/CRUISER H/T LWB 4.0L11ST MAN

L/CRUISER PRADO WAGON

LAND ROVER DISCOVERY SE7 4X4 WAGON

MAGNA SPORTS SEDAN

PAJERO

PAJERO 3.0L GLX LWB PET/MANUAL
PAJERO 4X4 3.5L GLS LWB AUTO WAGON
PAJERO 4X4 3.5L GLS LWB MAN WAGON

PATHFINDER

PATHFINDER 4X4 TI 3.3 V6 AUTO WAGON
PATHFINDER WAGON
PATHFINDER WGN
PATHFINDER TI V6 PET SW AUTO

PATROL WAGON

PATROL 4X4 ST 4.5EFI AUTO WAGON
PATROL 4X4 ST 4.5EFI MANUAL WAGON
PATROL 4X4 WAG RX 4.2EFI MAN PET'L
PATROL 4X4 WGN DX DIESEL/MAN/LSD
PATROL DX 4.2DSL 4X4 MAN WAGON
PATROL H/TOP DX PETROL/MAN/LSD
PATROL WGN 3.0L PETROL MAN
PATROL WGN DX PET/MAN/LSD
PATROL WGN RX 2.8 TURBO MANUAL
PATROL WGN RX 4.2 LPG MANUAL
PATROL WGN ST DIESEL/MAN/LSD
PATROL WGN ST PETROL/AUTO/LSD
PATROL WGN ST PETROL/MAN/LSD
PATROL WGN TI 4.2L PETROL MAN

PATROL TRAY

PATROL C/C 4.2L PETROL/MAN/LSD
PATROL UTE 4.2L DIESEL/MAN/LSD

RODEO 4X4

RODEO 4X4 C/CAB 2.8TURBO DSL/MAN

RODEO C/CAB 3.2 V6 4X4 PET/MANUAL
RODEO CREWCAB 4X4 2.6L MAN UTE
RODEO CREWCAB 4X4 2.8TURBO MAN

RODEO 4X2

RODEO C/C 2.8TURBO DIESEL/MAN
RODEO C/CAB 3.2 V6 4X2 PET/AUTO
RODEO C/CAB 3.2 V6 4X2 PET/MANUAL
RODEO CREWCAB 4X2 2.6L PET/MAN
RODEO CREWCAB 4x2 PETROL AUTO

ROVER DEFENDER 2.5D C/CAB 4X4 MAN

SUZUKI GRAND VITARA 4X4 2.5MPI AUTO WAGON

TOYOTA 4RUNNER 4X4 RV6 MAN WAGON

APPENDIX 4

Chi-Square Goodness-of-Fit Test for Rollover Rates

Testing Whether There Is A Significant Difference In The Rate Of Rollovers Between Vehicle Types Using the Chi-Square Goodness-of-Fit Test

Given that the sum of kilometres travelled differ for each vehicle type, comparison of rollover rates does not necessarily indicate whether a particular vehicle type has a higher or lower risk of having a ‘rollover’ accident than another vehicle. To overcome this problem, a Chi-square goodness-of-fit test was performed using the rollover data in relation to the kilometres travelled.

This test is an appropriate test to use to see whether a significant difference exists between the observed number of rollovers falling into each vehicle category and expected number of rollovers. That is, the chi-square test assesses the degree of agreement between the observed and expected observations in each category. To conduct this sort of test, we first require to state our null and alternative hypotheses, which in this case are as follows:

H_0 : *The rate of rollovers is the same for all categories of vehicles.*

H_A : *The rate of rollovers is not the same for all categories of vehicles.*

The null hypothesis is tested using the Chi-square goodness-of-fit statistic, which is shown below:

$$C^2 = \sum_{i=1}^k \frac{(O_i - E_i)^2}{E_i}$$

where O_i = the observed number of cases;

E_i = the expected number of cases when H_0 is true; and

k = the number of categories.

Table 8, below, shows the number of rollovers that occurred and the number of rollovers that were expected to have occurred for the given number of kilometres travelled. Expected values are calculated using the proportion of kilometres travelled (for each vehicle type) in relation to the total kilometres and multiplying this proportion by the total number of rollovers. For this test to be valid, expected values less than unity cannot be used. To proceed with this test, all four-wheel drive vehicle-types and the Rodeo 4x2 category were combined. As a result, five categories were tested with four degrees of freedom.

H_0 is rejected if the calculated value of X^2 is greater than the critical value of X^2 with four degrees of freedom at the significance level of 5%. The critical value of X^2_4 which is equal to 9.487 is obtained from statistical tables.

The observed X^2 , which is calculated using the above statistic, gives a value of 147.7. As this value is much greater than $X^2_4 = 9.487$, the null hypothesis is rejected. This means that there is strong evidence to suggest that there is a difference in the rate of rollovers between vehicle types.

The vehicles contributing to this large X^2 result are the Holden Divvy van category and the category making up all the four-wheel drives and the Rodeo 4x2. In other words these are the vehicles which have a higher than expected rate of rollovers (based on their relative exposure).

The Chi-square test was also conducted using vehicle months and a similar result was obtained ($X^2 = 146.4$) with the same two categories of vehicles contributing to the large X^2 value.

Vehicle Description	Sum of kilometres travelled	Observed number. of rollovers	Expected number of rollovers
COMMODORE SEDAN	248,792,877	2	13.65
FORD FALCON SEDAN	206902045	5	11.35
FORD FALCON DIVVY VAN	98654036	2	5.41
L/CRUISER WAGON 105R	1782835	1	0.10
PATROL WAGON	8308873	1	0.46
JACKAROO WAGON	5200340	1	0.29
L/CRUISER WAGON 80R	8665933	3	0.48
L/CRUISER LWB	4919467	3	0.27
HOLDEN DIVVY VAN	33751425	11	1.85
RODEO 4X2	2701725	5	0.15
TOTAL	619679556	34	34

Table 8 Observed and ‘Expected’ Number of Rollovers.

[Note: The ‘expected’ number of rollovers is based on the relative kms traveled by the different models.]